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ORIGINAL PAPER

Regeneration dynamics of dominant tree species along an altitudinal gradient in moist temperate valley slopes of the Garhwal Himalaya

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Abstract: The present study was undertaken in moist temperate forest of Mandal-Chopta area in the Garhwal region of Uttarakhand, India. The aim of the present study was to understand the regeneration dynamics of the dominant tree species along an altitudinal gradient in naturally regenerating, restricted access forest. The overall regeneration status was fairly high in the study area. Most of the native canopy and undercanopy dominants had frequent reproduction and expanding populations, which suggests the stability of forest structure/composition and further expansion of dominant species. The overall regeneration of trees in the forest had a greater contribution of middle and understorey species. Because of infrequent reproduction and declining populations of some of the dominant native species *viz*., *Abies pindrow, Alnus nepalensis* and *Betula alnoides*, structural/compositional changes in the future are expected in respective forests dominated by them. *Abies pindrow* and *Taxus baccata* need immediate attention by forest managers for their survival in the area. Seedlings were found to be more prone to competition from herb and shrubs than saplings.

Keywords: Garhwal; environmental gradient; forest structure; regeneration curves; species diversity

Introduction

The existence of a species in the community largely depends on its regeneration capacity under varied environmental conditions. The regeneration potential is the ability of a species to complete its life cycle in a given environment, which indicates the suitability of a species to that environment. Natural regeneration from seed requires adequate seed production, successful germination, seedling growth and establishment. The requirements are subject to the effects of weather, site conditions, competition between species and predation. The potential regenerative status of tree species often depicts the future composition of forests within a stand in space and time (Henle et al. 2004). Dominance of established seedlings and saplings under the adult trees also affect the future composition of a community (Pande et al. 2002). Sustained regeneration and growth of all species in the presence of older plants is required for better growth of any plant community (Taylur and Zisheng 1988). Presence of sufficient number of seedlings, saplings and young trees in a given population indicate a successful regeneration, while inadequate number of seedlings and saplings of tree species in a forest indicate poor regeneration (Saxena and Singh 1984). Studies on population behaviour of tree seedlings in different forests have shown that their recruitment, growth and survival are influenced by a variety of microclimatic and edaphic factors (Scholl and Taylor 2006). The interactive influence of biotic and abiotic factors of the environment affects the survival and growth of seedlings and sprouts (Muller-dombios et al. 1980). Seed germination, emergence, growth, survival and establishment of seedlings affect forest regeneration by influencing plant populations in forest (Osunkjoya et al. 1992).

An understanding of the processes that affect regeneration of forest species is of crucial importance to both ecologists and forest managers (Slik et al. 2003; Deb and Sundriyal 2008). Regeneration is a critical phase of forest management, because it maintains the desired species composition and stocking after disturbances. An essential part of forest stewardship involves the careful planning and management of young trees and seedlings. Himalayan moist temperate forests represent centres of high species diversity. Lack of sufficient regeneration is a major problem of mountain forests (Krauchii et al. 2000). An increasing interest in the development and management of such forests give rise to the need for understanding the regeneration process that ensures maintenance of the community structure and ecosystem stability (Moravie et al. 1997). Successful management and conservation of natural forest requires reliable data on aspects such

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as the regeneration trends (Eilu and Obua 2005). Therefore, it becomes imperative to study regeneration dynamics of the natural moist temperate Himalayan forests to ascertain the future course of action. In our earlier studies on forests of Garhwal region, relationships between forest dependency and socio-economic status of rural people in temperate villages (Sharma et al. 2009), role of physiographic factors (Sharma et al. 2010a), effects of slope aspects (Sharma et al. 2010b), physical properties of the soils (Sharma et al. 2010c), tree diversity and carbon stocks (Sharma et al. 2010d, 2011; Gairola et al. 2011a), and structure and composition (Gairola et al. 2011b, 2011c, 2011d) of the dominant forest types of the Garhwal Himalaya were worked out. However the studies related to regeneration of forests of this region are still lacking. Keeping the aforesaid facts in view, the present study was undertaken in a naturally regenerating, moist temperate, restricted access forest of Mandal-Chopta forest area of Garhwal Himalaya to understand the regeneration dynamics of dominant tree species along an altitudinal gradient.

Material and methods

Study area

The present study was conducted in Mandal-Chopta forest area, which forms a large (nearly 1,100 ha), prestigious, and botanically valuable reserve complex (Trishula Reserve Forest of Kedarnath Forest Division) in the Garhwal region (Western Himalaya) of Chamoli district of Uttarakhand state, India (Fig. 1). It occurs at 30°27.560' N latitude and 79°15.234' E longitude along an altitudinal gradient of 1,500 m.a.s.l. to 2,900 m.a.s.l. This area is a rich moist temperate forest situated 12 km away from the district headquarter, Gopeshwar. Recently Gairola et al. (2010) have recorded 338 species of vascular plants (334 Angiosperms and 4 Gymnosperms) belonging to 93 families (91 Angiosperms and 2 Gymnosperms) and 249 genera (246 Angiosperms and 3 Gymnosperms) from the study area.

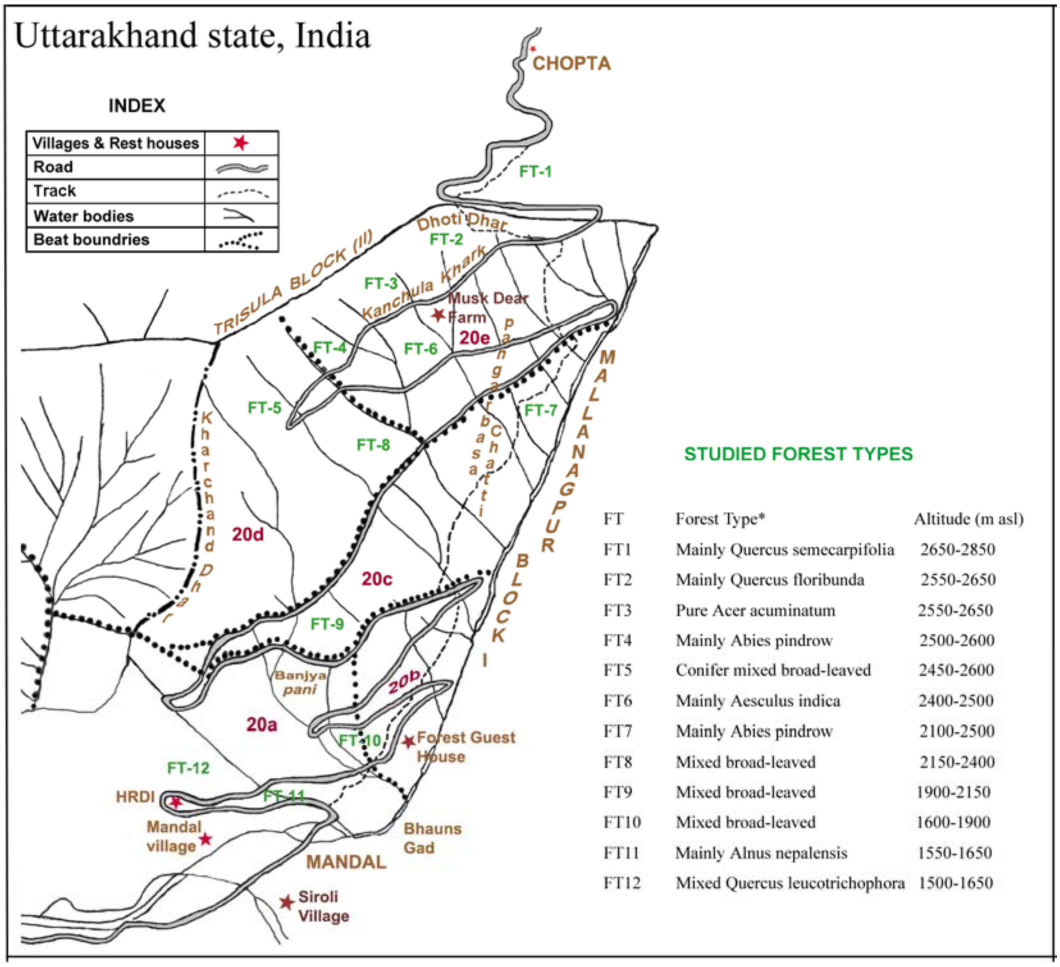

Fig. 1 Map of the study area.

The study area is characterized by undulating topography with gentle slopes on northern, northeastern and northwestern faces and somewhat steep slopes on southern and southwestern directions. The soil types found in the region are podozolic soils. Soil texture of the study area is predominantly sandy loam and sandy clay loam whereas soil colour varies from yellowish brown to dark brown (Sharma et al. 2010c). Soils are generally gravelly and large boulders are common in the area. Numerous high

ridges, deep gorges and precipitous cliffs, rocky crags and narrow valleys are part of the topography of the region. The topography of the area has also been influenced by landslides, which are common during rainy season. Geologically, the rocks in the study sites are complex mixture of mainly sedimentary, low grade metamorphosed with sequence capped by crystalline nappe. The study area lies in the central axis of the great Himalaya, which consists of belts of metamorphic rocks; includes gneisses, granites and schists, known as the Central Crystalline groups. Most of the rocks in the study area are fine to coarse-grained schists, all very much interleaved. Most of the schist is biotite mica, quartz and feldspar but the presence of a certain amount of garnet mica, schist is indicative of a low to moderate degree of metamorphism. Meteorological details (2000-2009) of the study are given in Fig. 2. Mean annual maximum and minimum temperature were recorded as 16.41±3.43°C and 6.14±2.65°C, respectively. Mean annual rainfall was recorded as 2,192.52±350.33 mm. Mean relative humidity round the year ranged from 15.5% to 86.6%.

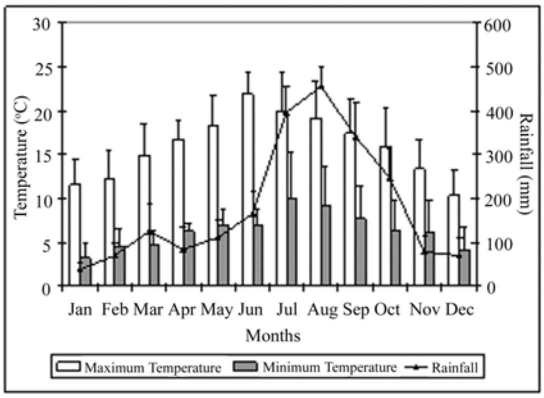

Fig. 2 Meteorological data of the study area (2000-2009) (Source: Uttarakhand Forest Department).

Sampling and data analysis

Regeneration survey was carried out in the rainy season during the months of July and August in year 2009. Twelve forest types according to altitude, slope aspect and species compositions were selected for this study during the reconnaissance survey of the study area (Table 1). Each forest type was named according to the composition of dominant tree species as per Prakash (1986), *viz.*, ≥ 75% as pure; 50-75% as mainly; 25-50% as mixed and < 25% miscellaneous. Physiographic factors i.e., altitude, and aspect across different cover types were measured by GPS (Garmin, Rino-130). The composition of the forest types along the altitudinal gradient was analyzed by using nested quadrat method as per Kent and Coker (1992). Trees, shrubs and herbs were analyzed by 10 m × 10 m, 5 m × 5 m and 1 m × 1 m sized quadrats respectively as proposed by Curtis and McIntosh (1950) and Phillips (1959). The basal cover for trees was calculated by dividing the square of CBH (circumference at breast height) with 4π. The basal cover was multiplied with respective densities of the species to obtain Total Basal Cover (m^2/ha). For each species, values of frequency, density and abundance were calculated following Curtis and McIntosh (1950). The Importance Value Index (IVI) was calculated by summing up relative density, relative frequency and relative dominance, following Phillips (1959). Species Richness was simply taken as a count of total number of species in that particular forest type. Shannon-Wiener Diversity Index was calculated as per Shannon and Weaver (1963):

$$\overline{\mathrm{H}} = -\sum_{i=1}^{s}\left(\frac{\mathrm{N_i}}{\mathrm{N}}\right)\log_2\left(\frac{\mathrm{N_i}}{\mathrm{N}}\right)$$

where, $\overline{\mathrm{H}}$ is Shannon-Wiener Diversity Index, N_i is IVI of a species, N is the total IVI of all the species.

Table 1. General details of the studied forest types and values of phytosociological and regeneration parameters.

FT	Forest Type*	Altitude (m asl)	SA	MTD (cm)	TTBC (m^2/ha)	TD (N/ha)	ShD (N/ha)	HeD (N/ha)	SeD (N/ha)	SaD (N/ha)	TSR	$\overline{\mathrm{H}}$
FT1	Mainly *Quercus semecarpifolia*	2650-2850	E	92	58.25	600	3100	322000	14800	773	5	1.60
FT2	Mainly *Quercus floribunda*	2550-2650	NE	106	72.51	493	15333	358500	5280	360	5	1.95
FT3	Pure *Acer acuminatum*	2550-2650	S	76	62.41	1180	2960	374000	15300	1963	9	1.74
FT4	Mainly *Abies pindrow*	2500-2600	NE	99	41.25	380	6453	311000	1050	523	5	1.45
FT5	Conifer mixed broad-leaved	2450-2600	NE	94	46.39	627	6613	476000	1850	619	8	2.70
FT6	Mainly *Aesculus indica*	2400-2500	NE	104	86.56	580	8773	480000	10667	1817	5	1.72
FT7	Mainly *Abies pindrow*	2100-2500	S	99	84.03	1390	9440	315000	30000	5750	12	3.19
FT8	Mixed broad-leaved	2150-2400	NE	95	76.83	1200	6693	464800	16267	9520	16	3.33
FT9	Mixed broad-leaved	1900-2150	NE	60	37.37	1007	9493	224000	12148	9792	13	3.14
FT10	Mixed broad-leaved	1600-1900	N	68	84.25	1470	11298	282500	14200	5616	13	3.09
FT11	Mainly *Alnus nepalensis*	1550-1650	NE	67	32.77	520	22640	544000	6000	1936	7	1.69
FT12	Mixed *Quercus leucotrichophora*	1500-1650	NE	44	35.08	990	24853	550500	600	96	10	2.43

*= Forest types used as FT1 to FT12 in the successive tables

Abbreviations: TD= tree density; ShD= shrub density; HeD= herb density; SeD= seedling density; SaD= sapling density; TTBC= tree total basal cover; TSR= tree species richness; $\overline{\mathrm{H}}$ = tree Shannon-Wiener diversity index; MTD= maximum tree diameter at breast height (1.37m). E= east; NE= north-east; S= south; N= north; SA= slope aspect (facing).

In each of the studied forest types the quadrats of 10 m ×10 m size were randomly laid out for trees (≥ 10cm dbh) and saplings

(≥ 1 cm and ≤10 cm dbh), in which the diameter at breast height of trees was measured and number of saplings in each quadrat was counted. Quadrats of 1 m × 1 m size were randomly laid out in each 10 m ×10 m sized quadrat at each site to count the number of seedlings. Further, the density and total basal cover of the trees was divided into successive diameter classes *i.e.*, 10–20 cm, 20–30 cm, 30–40 cm, and so on to determine the regeneration status and population structure of that particular forest cover type. Ratios of seedlings density with stem density and saplings density with stem density were calculated to identify regeneration performance of different tree species. A single tailed Carl-Pearson correlation coefficient was calculated between various Phytosociological and regeneration parameters using SPSS-16 package.

Results and discussion

The overall regeneration status was fairly high in Mandal-Chopta forest. Being a protected forest, there is restriction of human access. Thus tree felling and other forest operations are totally banned, which ultimately favoured the regeneration of many tree species. Besides, high rainfall, moderate temperature and wide variation in altitude and soil characteristics provided a favorable environment for the luxuriant growth of many tree species.

Regeneration of dominant tree species

Regeneration of *Abies pindrow* varied from one forest type to other (Table 2). In FT1, FT5 and FT7 *A. pindrow* had high regeneration with very high seedlings per tree ratios (Se/T), while in FT2 and FT4, its regeneration was adequate with moderate Se/T ratios. In FT3, FT6 and FT8 its regeneration was altogether absent. Even in the forest types, where it had high Se/T ratios, it had very low saplings per tree ratios (Sa/T), which shows conversion from seedlings to sapling stage was very low in the study area. In only FT4 its regeneration was adequate and it had inverse-J shaped curve of population structure. In FT7 although there were large numbers of seedlings, but very few saplings and adult individuals were encountered. FT3 showed sporadic and unimodal population structures, indicating that *A. pindrow* is not regenerating and it has individuals in higher diameter classes only. FT2 and FT5 showed both inverse-J and sporadic models of population structure. Twenty years ago (in early 90's) State Forest Department had auctioned mature trees of *A. pindrow* from this area, which is the main reason of sporadic population structure of this species. Researchers over the years have identified the following factors which affect the process of natural regeneration of *A. pindrow* in the upper Himalayan region:

1. Thick layer of humus or litter (undecomposed due to paucity of micro-organisms and lower temperature) and a greater dispersion of manganese and higher iron content in the soil profile (Troup 1921).
2. Thick growth of noxious weeds (Jha et al. 1984).
3. Impeded drainage conditions (Troup 1921).
4. Hydrophobic substances released from decomposition of litter of *A. pindrow* severely restrict the wetting of the soil. Therefore, the insufficient moisture content in the soil due to this thick layer of humus on the surface affect the process of regeneration (Jha et al. 1984).

In the study area the *A. pindrow* is in need of immediate assistance from the forest managers. Proper care to naturally regenerating seedlings is needed, so that they could survive to replace adult individuals in future. If present conditions persist for a longer time in future, there are chances of destruction of this important timber yielding species dominated forest from this area. *Taxus baccata* was only recorded in the conifer mixed broad-leaved forest type (FT5), but its regeneration was hampered. In nature this tree species has low regeneration rates. Besides that in the study area this tree species was badly affected by illegal extraction of its bark, leaves and roots, which also adversely effected its natural regeneration. No seedlings of this species were encountered in the study area and very few saplings with Sa/T ratio of 0.73 were observed. If no immediate attention to its protection (whether naturally or artificially) is given, there is all likelihood of its disappearance from the study area in near future.

Inadequate regeneration of *Quercus leucotrichophora* in the Himalaya has been reported by foresters in India for over 80 years (Troup 1921; Saxena and Singh 1982; Singh and Singh 1992; Thadani and Ashton 1995). However, we found that the regeneration of *Q. leucotrichophora* was very high in FT8, FT9, FT10 and FT11 with very high Se/T and Sa/T ratios in the study area, but in FT12 it showed stunted regeneration with very low Se/T and Sa/T ratios. In the study area, the anthropogenic disturbances are limited, thus high regeneration of *Quercus* species was expected. FT12 was located in the vicinity of villages (Khalla and Mandal); therefore, restriction of human interference was lesser and the anthropogenic disturbances in the form of grazing by domestic animals, lopping, fodder and fuel wood collection was noticed. According to Singh (1992), the grazing by domestic animals is the basic cause of low Oak regeneration in the Central Himalayan forest. Mainly *Quercus semecarpifolia* forest was located at the higher altitudes (2,650–2,850 m.a.s.l.) some 12 km away from human settlements and there was no human interference. This favored the regeneration of *Q. semecarpifolia*, which showed high Se/T and Sa/T ratios. Stands of *Q. floribunda* were also growing far away from human settlements and were totally undisturbed. Therefore, they showed luxuriant regeneration with high Se/T and Sa/T ratios, except in FT3 where it showed no regeneration. FT3 was pure *Acer acuminatum* forest type, in which high density of *A. acuminatum*, and competition between *A. acuminatum* and *Q. floribunda* for space and resources can be attributed as the reason for absence of its regeneration from FT3. Moreover, *Q. floribunda* acorns are commonly infested with weevils that can significantly lower down the germination rates, which is another reason for absence of its regeneration in this forest type. The presence of few seedlings of *Q. floribunda* relative to other tree species is not indicative of regeneration failure. Instead, low regeneration in well protected areas is associated with over stories with a high basal

area, stem density and canopy coverage (Thadani and Ashton 1995).

Table 2. Regeneration performance indicated as the ratio of seedling and sapling to tree densities in different forest types.

Tree species		FT1	FT2	FT3	FT4	FT5	FT6	FT7	FT8	FT9	FT10	FT11	FT12
Abies pindrow	Se/T	20	2.67	0/40	1.22	6.43	0/20	27.78	0/7	-	-	-	-
	Sa/T	0.15	0.07	0/40	0.46	0.69	0/20	0.19	0/7	-	-	-	-
A. spectabilis	Se/T	-	-	-	-	-	-	-	0/7	-	-	-	-
	Sa/T	-	-	-	-	-	-	-	0/7	-	-	-	-
Acer acuminatum	Se/T	-	-	14.03	1.25	0.98	-	-	-	-	-	-	-
	Sa/T	-	-	1.67	0.54	0.49	-	-	-	-	-	-	-
Aesculus indica	Se/T	-	-	0/25	-	0.34	18.97	0/110	5	-	-	-	-
	Sa/T	-	-	0/25	-	0.07	1.06	0/110	0/27	-	-	-	-
Alnus nepalensis	Se/T	-	-	-	-	-	-	-	-	0/33	0/110	3.14	0/10
	Sa/T	-	-	-	-	-	-	-	-	0/33	0/110	1.19	0/10
Betula alnoides	Se/T	-	-	-	-	-	0/40	0/100	0/100	6.35	2.86	-	-
	Sa/T	-	-	-	-	-	0/40	0/100	0.76	1.03	2.39	-	-
Buxus wallichiana	Se/T	-	-	-	-	-	-	-	0/7	-	-	-	-
	Sa/T	-	-	-	-	-	-	-	17	-	-	-	-
Carpinus viminea	Se/T	-	-	-	-	-	-	18.52	23.64	8.33	28.57	-	-
	Sa/T	-	-	-	-	-	-	1.67	22.41	8.1	9.9	-	-
Corylus jacquemontii	Se/T	-	-	-	-	0/20	-	-	-	-	-	-	-
	Sa/T	-	-	-	-	0/20	-	-	-	-	-	-	-
Cupressus torulosa	Se/T	-	-	-	-	-	-	-	-	-	0/10	-	-
	Sa/T	-	-	-	-	-	-	-	-	-	0/10	-	-
Daphniphyllum himalense	Se/T	-	-	-	-	-	-	0/100	10	17.51	8.84	-	-
	Sa/T	-	-	-	-	-	-	0/100	56.67	10.76	2.26	-	-
Diospyros montana	Se/T	-	-	60	-	-	-	-	0/13	0/13	0/10	-	-
	Sa/T	-	-	12.5	-	-	-	-	0/13	0/13	0/10	-	-
Dodecademia grandiflora	Se/T	-	-	-	-	-	-	0/50	-	-	-	-	-
	Sa/T	-	-	-	-	-	-	0/50	-	-	-	-	-
Euonymus tingens	Se/T	-	-	-	-	-	-	0/30	-	-	-	-	-
	Sa/T	-	-	-	-	-	-	0/30	-	-	-	-	-
Ficus roxburghii	Se/T	-	-	-	-	-	-	-	-	-	-	30	10
	Sa/T	-	-	-	-	-	-	-	-	-	-	0/10	0/10
F. subincisa	Se/T	-	-	-	-	-	-	-	-	-	-	-	0/10
	Sa/T	-	-	-	-	-	-	-	-	-	-	-	0/10
Fraxinus micrantha	Se/T	-	-	-	-	-	-	-	0/7	-	0/10	-	-
	Sa/T	-	-	-	-	-	-	-	0/7	-	0/10	-	-
Juglans regia	Se/T	-	-	-	-	-	-	-	0/7	-	-	-	-
	Sa/T	-	-	-	-	-	-	-	0/7	-	-	-	-
Lyonia ovalifolia	Se/T	20	16.5	30	-	4.5	-	20.83	7.5	22.22	3.33	-	0.38
	Sa/T	3.18	2.49	13.75	-	3.2	-	10	6.38	7.54	6.07	-	0.12
Myrica esculenta	Se/T	-	-	-	-	-	-	-	-	-	-	-	0.31
	Sa/T	-	-	-	-	-	-	-	-	-	-	-	0.05
Neolitsea pallens	Se/T	-	-	30	-	-	-	7.58	40	22.22	-	-	-
	Sa/T	-	-	5	-	-	-	17.95	21.25	52.8	-	-	-
Persea duthiei	Se/T	-	5.14	20	0/5	0/20	7.69	14.58	4.78	11.67	-	-	-
	Sa/T	-	0.37	2.5	0/5	0/20	2.51	11.13	6.6	12.72	-	-	-
P. odoratissima	Se/T	-	-	-	-	-	-	-	-	-	11.89	10	-
	Sa/T	-	-	-	-	-	-	-	-	-	6.56	9.6	-
Pinus roxburghii	Se/T	-	-	-	-	-	-	-	-	-	-	0/10	-
	Sa/T	-	-	-	-	-	-	-	-	-	-	0/10	-
Pyrus pashia	Se/T	-	-	-	-	-	-	-	-	0/13	0/10	3.33	1.25
	Sa/T	-	-	-	-	-	-	-	-	0/13	0/10	0/30	0.4
Quercus floribunda	Se/T	-	8.76	0/65	8.85	-	15	106.5	31.43	-	-	-	-
	Sa/T	-	0.24	0/65	2.51	-	1.89	2.5	1.21	-	-	-	-

Continued Table 2

Tree species		FT1	FT2	FT3	FT4	FT5	FT6	FT7	FT8	FT9	FT10	FT11	FT12
Q. leucotrichophora	Se/T	-	-	-	-	-	-	-	2	12.35	17.5	16.25	0.51
	Sa/T	-	-	-	-	-	-	-	9.92	9.07	5.42	4.4	0.05
Q. semecarpifolia	Se/T	28	-	-	-	-	-	-	-	-	-	-	-
	Sa/T	0.54	-	-	-	-	-	-	-	-	-	-	-
Rhododendron arboreum	Se/T	23	21.23	0/5	10	4.69	-	31.25	31.58	11.11	14.55	90	0/40
	Sa/T	2.29	1.43	0/5	6.86	3	-	6.25	9.39	13.92	5.57	26.4	0/40
Sorbus cuspidata	Se/T	0/10	-	-	-	-	-	-	-	-	-	-	-
	Sa/T	0/10	-	-	-	-	-	-	-	-	-	-	-
Symplocos paniculata	Se/T	-	-	-	-	-	-	-	-	0/7	-	-	-
	Sa/T	-	-	-	-	-	-	-	-	0/7	-	-	-
Taxus baccata	Se/T	-	-	-	-	0/73	-	-	-	-	-	-	-
	Sa/T	-	-	-	-	0.73	-	-	-	-	-	-	-
Ulmus wallichiana	Se/T	-	-	-	-	-	-	-	-	0/7	13.33	-	0/10
	Sa/T	-	-	-	-	-	-	-	-	0/7	0/15	-	0/10
Total	Se/T	24.67	10.7	12.97	2.76	2.95	18.39	21.58	13.56	12.07	9.66	11.54	0.61
Total	Sa/T	1.29	0.73	1.66	1.38	0.99	3.13	4.14	7.93	9.73	3.82	3.72	0.1

Abbreviations: Sa/T= Saplings/ Tree; Se/T= Seedlings/ Tree.

Regeneration of *Aesculus indica* was high in FT6 where it was the main dominant tree species but in other forest types its regeneration was hampered (FT5, FT8) or altogether absent (FT3, FT7). It is canopy forming tree species hence needs high light availability to germinate, but in FT7 and FT8 canopy cover was very high due to prevalence of broadleaf species as well as under canopy dominants. According to Uhl and Murphy (1981) the regeneration of light demanding canopy dominants is limited to the early stages of succession, when light availability is high and regeneration of such species takes place only in gaps. In all the forest types (FT3 to FT5), where *Acer acuminatum* was present, it showed inverse-J shaped population structure. In FT3, where *A. acuminatum* formed pure forest type, most of the individuals of this species were in lower diameter classes, whereas in FT4 and FT5, large individuals of this species were also encountered in the study area. Besides that, in FT3 it had high Se/T and Sa/T ratios, whereas in FT4 and FT5 it had very low Se/T and Sa/T ratios. It means *A. acuminatum* is in early stages of succession in FT3. Campbell et al. (1992) also inferred that the dominance of tree individuals in medium to lower girth classes suggests that the forest is still in evolving stage.

Regeneration of *Lyonia ovalifolia* was high in all the forest types except FT12, where its Se/T and Sa/T ratios were very low as compared to other forest types, which could be due to human interference in that particular forest type. Regeneration of *Rhododendron arboreum* was high in all the forest types except FT3 and FT12, where its regeneration was altogether absent. Dominance of *A. acuminatum* in FT3 and anthropogenic disturbances in FT12 can be assigned as a plausible reason for it. However, along the altitudinal gradient *L. ovalifolia* and *R. arboreum* can be called as the most successfully regenerating tree species. Regeneration of *Alnus nepalensis* was totally absent from FT9, FT10 and FT12, whereas it was moderate in FT11, where it was the dominant tree species. In FT11 it showed inverse-J shaped population structure. Inverse-J type of distribution is considered to be an indication of stable population structure or good regeneration status (Getachew et al. 2002). In FT10 it showed sporadic and unimodal structures of regeneration, which means there are adult individuals in few diameter classes only. It shows that although it is dominant species in this forest type, but in the future due to non-recruitment of seed bearers there is a danger to its existence in this forest type. Bhuyan et al. (2003) also inferred that only that species, which have nearly equal distribution of individuals in all the three life stages are expected to remain dominant in the near future.

The overall regeneration of trees in the forest had a greater contribution of middle and understorey species as they are better adapted to grow under the shady conditions. The strata wise regeneration observation showed the dominance of middle strata species, which accounted for maximum regeneration at the middle and lower altitudinal (1,600 m a.s.l. to 2,400 m a.s.l.) forest types (FT6 to FT10). The emergence of seedlings of the subcanopy and understorey dominants, such as *Daphniphyllum himalense* (FT8 to FT10), *Neolitsea pallens* (FT3 and FT7 to FT9), *Carpinus viminea* (FT7 to FT10), *Persea duthiei* (FT2 to FT9) and *Persea odoratissima* (FT10 and FT11) in all the forest types showed the availability of different light intensities and qualities in forest gaps, forest edge and under the canopy, which did not influence their seed germination and early seedlings growth.

For some tree species there were large numbers of seedlings and saplings as compared to the adult individuals, which indicates massive seed production and/or high seedlings establishment. It could lead to higher recruitment of adults in future. High rainfall and moderate temperature coupled with the fertile soils of the forest may have favoured high regeneration of these tree species. Moreover, this forest is restricted access forest and anthropogenic disturbances are almost absent in this forest, which may also be the possible cause for the high regeneration. At some sites the success of seedling conversion to sapling has relatively been lower. High mortality of seedlings could be the possible reason for low recruitment of saplings in some tree species. Benton and Werner (1976) have held that in any forest, if maximum number of individuals of any species are represented in higher diameter classes as compared to lower diameter classes,

the population structure of that species should be considered on the verge of extinction. The presence of sufficient number of seedlings, saplings and young trees (pole) and mature trees in a given population indicates successful regeneration (Khan and Tripathi 1987). The number of saplings and seedlings per unit area is an index to assess the regeneration potential in a forest. The individual lapse rate from seedling to sapling to tree stratum also varied for different species. Tree species without seedlings were *B. alnoides* (FT8), *B. wallichiana* (FT8) and *T. baccata* (FT5) and without saplings were *A. indica* (FT8), *F. roxburghii* (FT11 and FT12), *P. pashia* (FT11) and *U. wallichiana* (FT9 and FT12). Whereas, tree species in which regeneration was totally absent were *A. pindrow* (FT3, FT6 and FT8), *A. spectabilis* (FT8), *A. indica* (FT3 and FT7), *A. nepalensis* (FT9, FT10 and FT12), *B. alnoides* (FT6 and FT7), *C. jacquemontii* (FT5), *C. torulosa* (FT10), *D. himalense* (FT7), *D. montana* (FT8, FT9 and FT10), *D. grandiflora* (FT7), *E. tingens* (FT7), *F. subincisa* (FT12), *F. micrantha* (FT8 and FT10), *J. regia* (FT8), *P. duthiei* (FT4 and FT5), *P. roxburghii* (FT11), *P. pashia* (FT9 and FT10), *Q. floribunda* (FT3), *R. arboreum* (FT3 and FT12), *S. cuspidata* (FT1), *S. paniculata* (FT9) and *U. wallichiana* (FT9 and FT12). The population size of species that lack either seedlings or saplings may decline in the coming years. The forest types characterized by abundance of only adults of the canopy and subcanopy species and absence or very low populations of seedlings and saplings of those species are expected to face local extinction in due course.

Forget (1991) reported that many non-pioneer species can establish in understorey, forest edges and gaps. In all the forest types there were dense canopy cover, not many invasive or pioneer species could invade and grow inside. Although there were few invading species in this forest, but few forest types had high percentage of seedlings and saplings of invasive species. Four forest types *i.e.*, (i). mainly *Abies pindrow* forest type (with 4.76% seedlings and 34.42% saplings of invasive species), (ii). conifer mixed broad-leaved forest type (with 27.03% seedlings and 15.51% saplings of invasive species), (iii). mainly *Aesculus indica* forest type (with 25.00% seedlings and 54.72% saplings of invasive species) and (iv). mainly *Alnus nepalensis* forest type (with 20.00% seedlings and 23.14% saplings of invasive species) are at risk of change in composition in future. *L. ovalifolia* and *B. wallichiana* in FT4; *Q. floribunda* in FT5; *A. acuminatum, L. ovalifolia, N. pallens* and *R. arboreum* in FT6; *B. wallichiana* and *A. acuminatum* in FT7; *A. acuminatum* in FT8; *A. acuminatum* in FT9; *N. pallens* in FT10; and *L. ovalifolia* and *D. himalense* in FT11 were the main invasive tree species in the respective forest types. These species have invaded from the nearby forest types. It can be inferred from this data that these forest types will certainly have different species composition after 15−20 years from present.

Diameter class distribution

The proportions of different life stages (seedlings, saplings, boles and mature trees) in a given population may help in predicting possible future status of the forest stands (Sundriyal and Sharma 1996). In a forest stand, generally the most dominant species are represented by all diameter classes (Khan et al. 1987). The dominant tree species in different forest types were assessed for their regeneration status along with the mature trees in different girth classes. The DBH class distributions of the species exhibited different patterns and showed that there are species with individuals concentrated in the lower diameter classes, some species at the middle and others at higher classes. From the DBH class distributions of the species, two types of regeneration status were recognized, *i.e.*, good (*Q. semecarpifolia, Q. leucotrichophora, Q. floribunda, A. acuminatum, A. indica, C. viminea, D. himalense, L. ovalifolia, M. esculenta, N. pallens, P. duthiei, P. odoratissima* and *R. arboreum*) and poor (*A. pindrow, A. spectabilis, A. indica, A. nepalensis, B. alnoides, B. wallichiana, C. jacquemontii, C. torulosa, D. montana, D. grandiflora, E. tingens, F. roxburghii, F. subincisa, F. micrantha, J. regia, P. roxburghii, P. pashia, S. cuspidata, S. paniculata, T. baccata* and *U. wallichiana*). Some species possessed high number of individuals in the lower DBH classes, particularly in the first category, which suggests that they have good regeneration potential. Other species possessed either no or few number of individuals in the lower DBH classes, particularly in the second category, which indicates that the species are in poor regeneration status. The following were the tree size-class distribution patterns, suggesting different regenerative mechanisms of species in the study area (Fig. 3):

1. The inverse-J type population structure formed by species having the highest frequency in the lower DBH classes with a gradual decrease in the number of individuals in the higher classes. Tree species in the study area which comes under this category were *Q. semecarpifolia* (FT1), *R. arboreum* (FT1, FT2, FT8, FT9 and FT10), *L. ovalifolia* (FT2, FT8, FT10 and FT11), *P. duthiei* (FT2, FT6, FT7, FT8 and FT9), *Q. floribunda* (FT2, FT4, FT6, FT7 and FT8), *A. indica* (FT5), *T. baccata* (FT5), *A. pindrow* (FT2, FT4, FT5 and FT7), *A. acuminatum* (FT3, FT4 and FT5), *B. alnoides* (FT8, FT9 and FT10), *D. himalense* (FT9 and FT10), *N. pallens* (FT7), *C. viminea* (FT8 and FT9), *Q. leucotrichophora* (FT8, FT9, FT10, FT11 and FT12), *A. nepalensis* (FT11), *P. odoratissima* (FT10), *M. esculenta* (FT11) and *P. pashia* (FT12). Reverse J type of distribution is considered to be an indication of stable population structure or good regeneration status (Getachew et al. 2002).

2. The sporadic type of population structure indicates that the adjacent classes were badly represented; frequency rises more or less sharply in intermediate classes. Tree species in the study area which comes under this category were *Q. semecarpifolia* (FT1), *L. ovalifolia* (FT10), *A. indica* (FT5), *Q. floribunda* (FT2, FT4, FT6 and FT7), *A. pindrow* (FT2, FT3 and FT5), *T. baccata* (FT5), *A. indica* (FT5, FT6 and FT7), *B. alnoides* (FT10), *Q. leucotrichophora* (FT8, FT9 and FT10) and *A. nepalensis* (FT10).

3. The emergent type of population structure was only represented by large sized ones with uni-modal distribution in a mature community. Tree species in the study area which comes under this category were *Q. floribunda* (FT3), *A. pindrow* (FT3), *A. indica* (FT7), *B. alnoides* (FT7), *D. himalense* (FT7) and *A. nepalensis* (FT10). The U-shaped DBH class distribution indi-

cated that there was good regeneration of individuals, but seedling establishment is hampered.

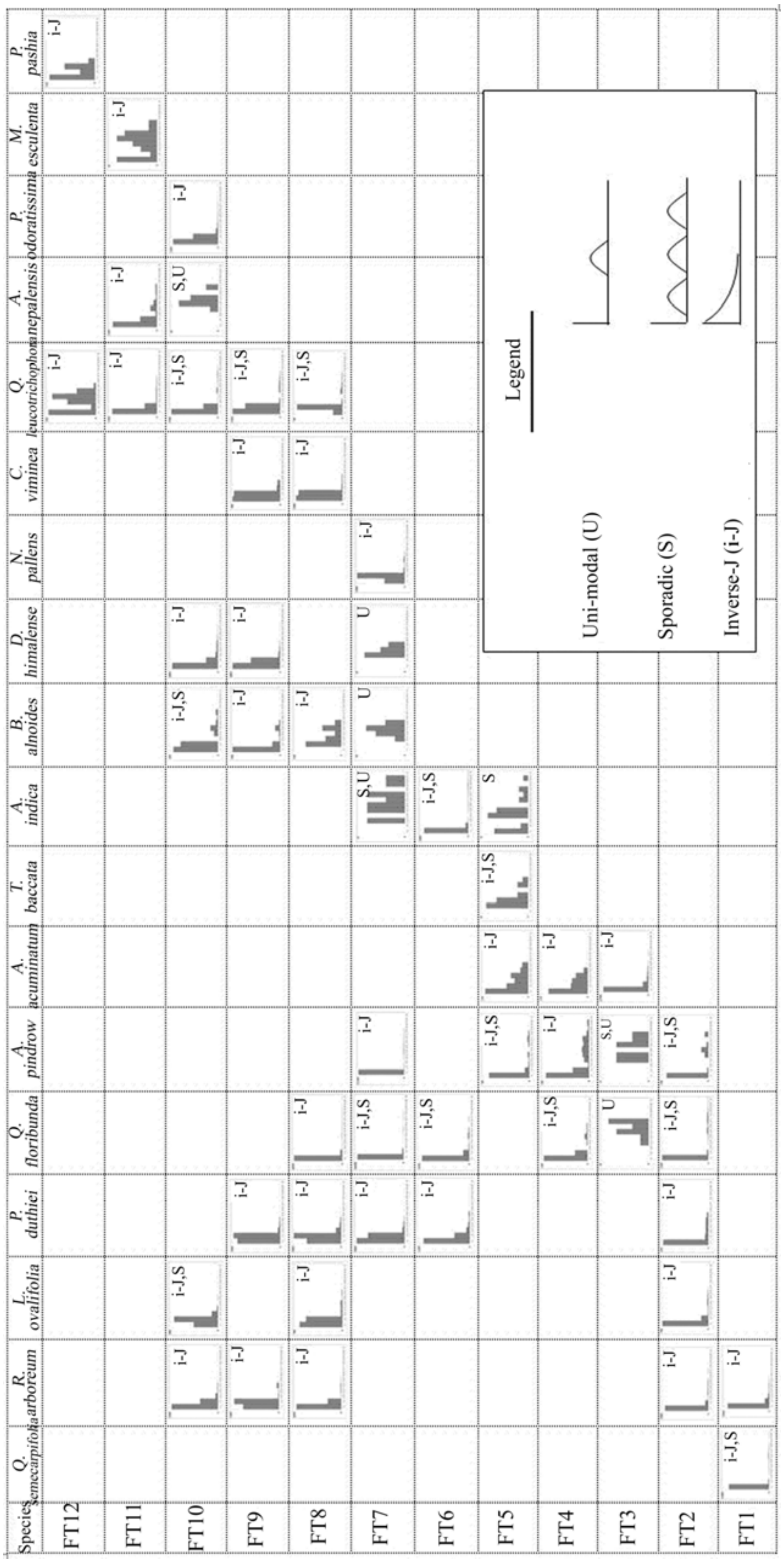

Fig. 3 Population structure and its regeneration types, inverse-J (i-J), sporadic (S), and uni-modal (U) based on the diameter at breast height (1.37 m) class distribution of the major dominant tree species in different forest types along the altitudinal gradient of the study area.

Some of the forest types showed combination of two size-class distribution patterns *viz.*, sporadic with uni-modal and inverse-J with sporadic. If a species show 'inverse J' shaped distribution with higher number of individuals in seedling stage and the

number gradually decreased in saplings, small trees, old trees categories, such distribution shows that these species are in most dominant form in the stand at present. The 'J' shaped distribution depicts pioneer status while 'inverse-J' expresses successional status of the species. The inverse-J diameter distribution of stem density with increasing diameter classes shows that a small fraction of the seedling and sapling classes survived up to the larger tree classes. Undisturbed old-growth forests such as Mandal-Chopta forest with sustainable regeneration were found to have inverse-J shaped size-class distribution (as was also reported by Bernadzki et al. 1998). A bell-shaped size-class distribution has been attributed to disturbed forest, where regeneration is hampered (Saxena et al. 1984). In this study many tree species showed an 'inverse-J' shaped population structure having number of small tree individuals (juviniles), considerable number of medium sized individuals and very few large tree individuals. Some other species devoid of their regeneration showed their poor status, while a few were represented in seedling and sapling stages only and such species seem to be new intruders in the studied stands.

Correlation between various phytosociological and regeneration parameters

The results of correlation between various phytosociological and regeneration parameters are shown in Table 3. In nature, species diversity is maintained through regeneration of component species. It is assumed that the adult individuals on a site or of a species constitute the reproductive pool. Densities of seedlings (originating from seeds) are usually influenced by the densities of large trees, some of which are seed trees. Therefore, under normal conditions in a forest one would expect a significant relationship between number of adult individuals and number of seedlings. This study indicated that the relationship between the numbers of adult individuals compared to number of seedlings was statistically significant (0.677). According to Eilu and Obua (2005) densities of seedlings (originating from seeds) are usually influenced by the densities of large trees some of which are seed trees.

It is further assumed that the saplings on a site or of a species are the immediate source of the adult individuals. Therefore, under normal conditions there should be a significant relationship between number of saplings and number of adult individuals. More adults would result in a larger seed pool and ensure an adequate number of saplings, while fewer adults could result in reduced fecundity. The relationship between number of saplings and adult individuals was statistically significant (0.462). As population size and density are important indicators of regeneration success, it would be important to augment populations of low-density species to ensure that viable populations of a species are maintained in the ecosystem (Davidar et al. 2007). Under normal conditions, one would expect a significant relationship between saplings and seedlings, as the later constitute a source of former. This study also showed statistically significant (0.573) relationship between number of saplings and seedlings. Similarly, Sagar and Singh (2005) also found significant relationship between saplings, seedlings and adult individuals in dry deciduous forest of Uttar Pradesh.

Table 3. Correlation between various phytosociological and regeneration parameters.

	TTBC	TD	TSR	$\overline{H}$	ShD	HeD	SeD	SaD
TD	0.431	1	-	-	-	-	-	-
TSR	0.19	0.852**	1	-	-	-	-	-
$\overline{H}$	0.261	0.749**	0.903**	1	-	-	-	-
ShD	-0.374	-0.093	-0.011	-0.001	1	-	-	-
HeD	-0.212	-0.265	-0.149	-0.201	0.524*	1	-	-
SeD	0.638*	0.677**	0.478	0.443	-0.401	-0.419	1	-
SaD	0.251	0.642*	0.856**	0.784**	-0.2	-0.388	0.573*	1
TR	0.577*	0.736**	0.650*	0.600*	-0.376	-0.452	0.963**	0.771**

*. Correlation is significant at the 0.05 level; **. Correlation is significant at the 0.01 level.

Abbreviations: TTBC= tree total basal cover; TD= tree density; TSR= tree species richness; $\overline{H}$ = tree Shannon-Wiener diversity index; ShD= shrub density; HeD= herb density; SeD= seedling density; SaD= sapling density; TR= total regeneration (SeD+SaD).

Several studies have suggested competition of seedlings and saplings with the sub-canopy shrubs and herbaceous vegetation (Lorimer et al. 1994). Seedling density showed negative correlation with shrub density (-0.401) and herb density (-0.419), whereas sapling density did not show any correlation with herb or shrub density. According to Moktan et al. (2009), the presence of abundant shrubs and herbs impedes seedling establishment of both shade-tolerant and intolerant species. Total regeneration showed negative correlation with herb density (-0.452). Crow (1988) also found that shrubs and herbaceous vegetation inhibits growth of seedlings and saplings of tree species. This finding also highlights the fact that seedlings are more prone to competition from herb and shrubs than saplings, which overcome the inhibitory effect of them. This may be mainly due to competition for light causing loss to seedlings, whereas saplings may escape it. Total regeneration showed statistically significant positive correlation with tree species richness (0.650). It shows that with the increasing diversity there are more chances of survival of the forest community. In natural undisturbed forests different tree species are adapted to utilize different niche spaces. As their requirement for nutrient and other resources are different and they are specialized to exploit all the available resources to get most out of it.

Conclusions

In the present study following general conclusions can be drawn on the basis of relative distribution of individuals in different size-classes:

1. Regeneration of most of the forest types may be considered good, as there was successive decrease in population density from seedling to adult tree stage. The presence of established seedlings was indicative of excellent recruitment of the species.

2. Two types of population structures were apparent: a). Frequently reproducing tree species with a large number of individuals in smaller DBH class and progressively fewer individuals in larger size classes; b). Infrequently reproducing tree species, where most of the individuals were in middle size classes with decreasing numbers towards both larger and smaller size classes.

3. The dominant species in different forest types showed the following patterns of population structures and regeneration: a) most of the native canopy dominants had frequent reproduction and expanding populations. Likewise, most of the undercanopies dominant were following a similar trend suggesting the stability of forest structure/composition and further expansion of dominant species; b) because of infrequent reproduction and declining populations of some of the dominant native species *viz.*, *A. pindrow, A. nepalensis* and *B. alnoides*, structural/compositional changes are expected in their respective forest types dominated by them in the near future.

4. The emergence of seedlings of the sub-canopy and understorey species in all the forest types showed that different light intensities and qualities in forest gaps, forest edge and under canopy did not influence their seed germination and early seedling growth.

5. The absence/low amount of seedlings and saplings of some important tree species viz., *A. pindrow* and *T. baccata*, showed that they are in immediate need of attention by forest managers and proper planning is needed for their conservation.

6. Seedlings were more prone to competition from herb and shrubs than saplings.

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